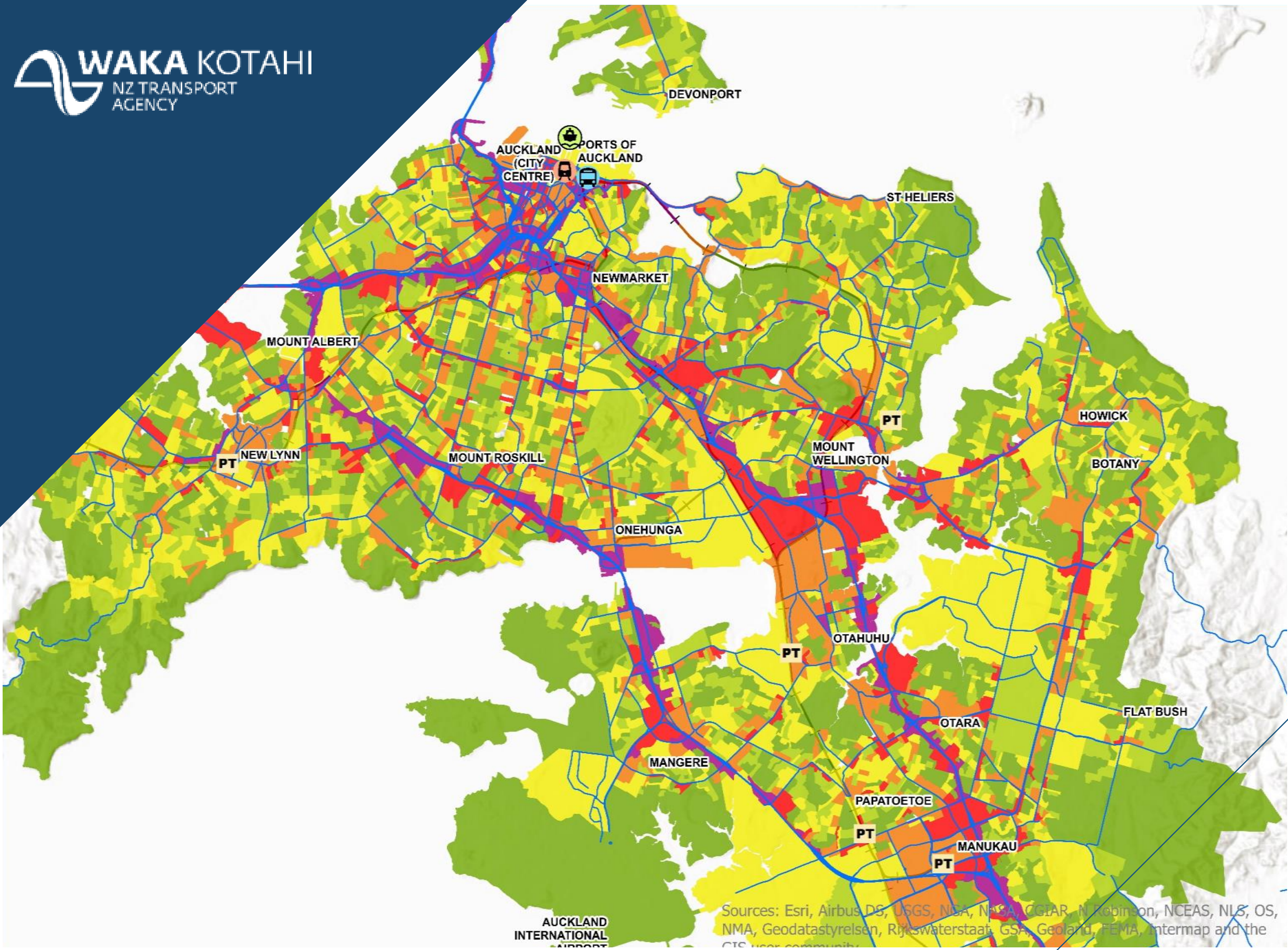

VEHICLE EMISSIONS MAPPING TOOL

Summary report

TONKIN & TAYLOR LTD

16 APRIL 2021

DRAFT VERSION 2

New Zealand Government

1.1.1 Copyright information

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Contents

1 INTRODUCTION

Tonkin & Taylor Ltd (T+T) has been engaged by Waka Kotahi NZ Transport Agency (Waka Kotahi) to prepare a summary report of the methods, inputs, and outputs of the Waka Kotahi Vehicle Emissions Mapping Tool (VEMT), and the associated concentration and pollutant exposure calculators.

Development of the VEMT was commissioned by Waka Kotahi in 2014. It has been used to calculate the National Vehicle Emission Dataset (NVED) of harmful air pollutants and greenhouse gases since 2016[1]. In addition, the vehicle emissions can be used to calculate near road-side concentrations of harmful air pollutants to determine population exposure to elevated levels.

The schematic in Figure 1.1 below shows the high-level structure this report. Each section of this report details the input requirements for running the tool, and any validation that has been undertaken of the tool and models. Limitations are discussed in Section 1 and example outputs are shown in Section 0.

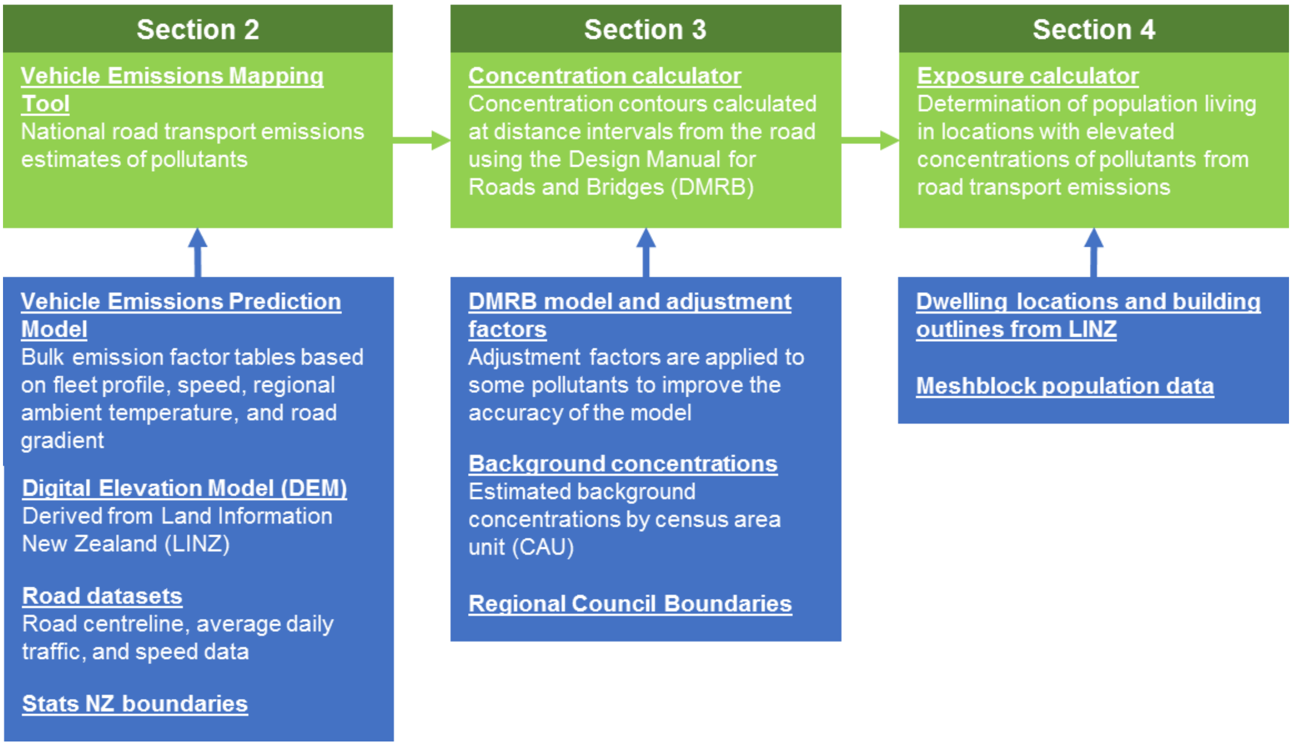

Figure 1.1: Schematic showing inputs and outputs of the VEMT, concentration calculator and exposure estimator

[1]*National Vehicle Emission GIS Mapping, National Vehicle Emission Dataset 2016 (2018)*, Jacobs

2 VEHICLE EMISSIONS MAPPING TOOL

2.1 Introduction

The VEMT automates calculation of air pollutants and greenhouse gas emissions from road transport on all public roads in New Zealand. It is housed in a geographical information system (GIS) framework to allow for ease in merging with road network data and to explore how output emissions data varies over a range of spatial scales.

Annual road transport emissions are calculated for the New Zealand road fleet and applied to all road links in New Zealand.

Current uses of the VEMT include:

- Developing inventories of harmful air pollutant and greenhouse gases emissions
- Reporting trends in emissions over time
- Supporting investigations into the health effects of exposure to vehicle emissions.

The tool extracts data from the Waka Kotahi information technology system to build a detailed data set of input variables. A matrix of emissions factors extracted from VEPM is used with these input variables to calculate the mass emission of pollutant per length of roadway.

The following Sections 2.2 to 2.3 describe the inputs required to run the VEMT including VEPM and geospatial data, Section 2.3.2 details how the model is run, Section 2.5 discusses its validation, and example outputs are shown in Section 0.

2.2 Vehicle Emissions Prediction Model

2.2.1 Overview

VEPM is an 'average speed' model that predicts emission factors for the New Zealand vehicle fleet under typical road, traffic and operating conditions. The average emission factor for a pollutant and vehicle type/technology varies as a function of the average speed during a trip. The VEMT currently uses VEPM 6.1[2] and is updated annually.

VEPM provides tailpipe exhaust emission factors for carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), carbon dioxide (CO_2), and particulate matter with a diameter of less than 10 microns (PM_{10}) and 2.5 microns ($PM_{2.5}$), as well as particulates from brake and tyre wear (PM_{BT}).

It is an excel based tool that was developed to quantify vehicle emissions and predict how these are likely to change over time. The model can estimate the effect of new technology and improved fuel on emissions from New Zealand's vehicle fleet by back-casting for previous years, estimates for current years, and predictions for future years.

A full description of how to use VEPM is included in the '*Vehicle Emissions Prediction Model (VEPM 6.0) User Guide*'[3] with updates for version 6.1 included in '*Vehicle Emissions Prediction Model: VEPM 6.1 update technical report*'[see footnote 2].

The full details are not replicated here, but the aspects relevant to running VEMT are included below: inputs are described in Section 2.2.2, emissions calculations are discussed in Section 2.2.3, outputs used in Section 2.2.4, and validation in Section 2.2.5 Validation of VEPM. A schematic of the high-level flow of VEPM is shown in Figure 2.1.

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[2] *Vehicle Emissions Prediction Model: VEPM 6.1 update technical report (September 2020),* Report for Waka Kotahi NZ Transport Agency prepared by Emission Impossible Ltd

[3] *Vehicle Emissions Prediction Model (VEPM 6.0) User Guide (July 2019),* NZ Transport Agency

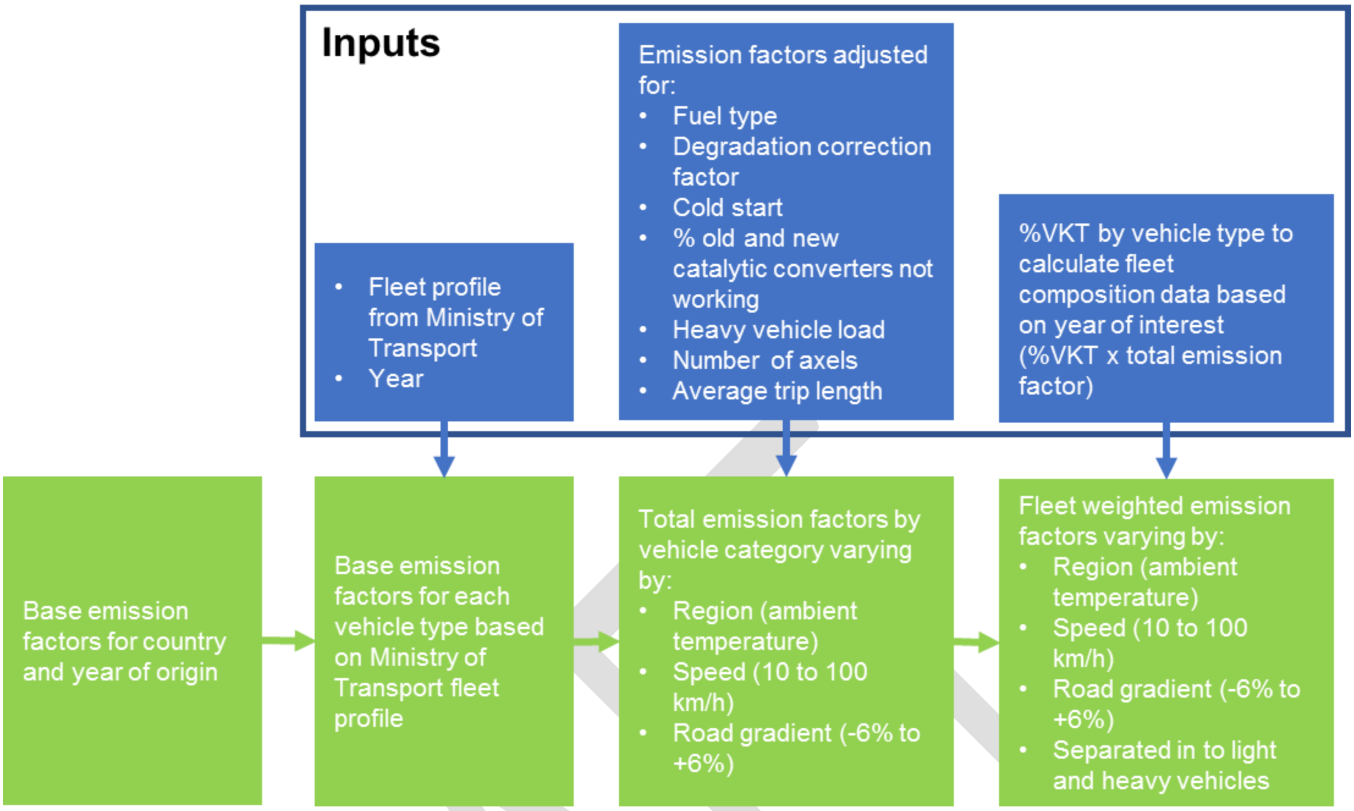

Figure 2.1: Flow diagram of calculation steps of fleet weighted emission factors in VEPM

2.2.2 VEPM inputs

2.2.2.1 Base emission factors

There is insufficient emission testing data in New Zealand to develop New Zealand-specific vehicle emission factors. The New Zealand fleet includes vehicles that have been manufactured to various emission standards including Japanese, European and Australian. These jurisdictions have introduced different emission requirements at different times and have used different emission measurement techniques. This inconsistency means international emission models are not directly applicable to the New Zealand fleet. VEPM has been developed using New Zealand fleet data, New Zealand real world fuel consumption values for light duty diesel vehicles, and emissions data from a range of international sources.

Most of the passenger car and light commercial fleet is manufactured to European emission standards. For vehicles manufactured to European standards, VEPM uses the European Computer Model to Calculate Emissions from Road Transport (COPERT). The COPERT model is supplemented with emissions from other sources, including any available New Zealand data, where applicable.

A substantial proportion of the passenger car and light vehicle fleet is second hand domestic Japanese vehicle manufactured to Japanese emission standards. At the time VEPM was developed, there was insufficient emissions data to develop comprehensive emission factors based on Japanese data. For these vehicles, the closest equivalent European emission factor for each Japanese vehicle class and pollutant is assigned[4].

The changes in emissions profiles of cars manufactured overseas will be reflected in the New Zealand fleet. VEPM should contain the latest internationally available information relevant for the New Zealand conditions. Each updated version of VEPM includes updates and revision of relevant emission factors from international models and standards.

[4] *New Zealand vehicle emissions factors database (2012),* Energy and Fuels Research Unit, Auckland University

2.2.2.2 Variable inputs

Emission factors for each vehicle type in the New Zealand fleet will vary depending on road conditions, including speed and gradient. Also, the fleet profile will change each year depending on the introduction and phasing out of technologies and vehicles.

VEPM is run in a 'bulk run' format to allow generation of a matrix of emission factors that represent all road conditions in New Zealand. This allows multiple runs to be completed at the same time varying the relevant input data. Variable inputs used for VEMT are shown in Table 2.1. Other default inputs are described in Appendix B. The variables considered are input in a tabular format shown in Figure 2.2.

Table 2.1: Variable inputs used in bulk VEPM run for VEMT

Input	Description
Year	Must be between 2001 and 2050. VEPM selects a fleet profile for the New Zealand fleet using the year selected.
Fleet profile	Percentage of vehicle kilometres travelled (VKT) by each vehicle class is based on default values depending on the year selected. This is then extended to default fleet data by vehicle category. The default vehicle fleet data is provided by Ministry of Transport's Vehicle Fleet Emissions Model (MoT VFEM). VFEM outputs include actual fleet composition data, projected fleet composition data and estimated average annual VKT for each vehicle category. In VEPM, the fleet profile is aggregated into emission factors for light and heavy vehicles based on percentage VKT. This allows application to different light/heavy vehicle ratios across the country.
Average speed	Average speeds in VEPM range between 10 and 100 km/h, with an increment of 1 km/h. Emission factors for each vehicle class are calculated for each speed increment. For heavy duty vehicles the valid speed range will depend on vehicle size, gradient and load. If the specified speed is outside of the valid range, the model will calculate emissions at the closest valid speed (eg if the highest valid speed is 87 km/h, defined speeds of 100 km/h will calculate emissions at 87 km/h for that vehicle class).
Ambient temperature	Annual average ambient temperature varies by region. Each bulk run will be run for the 16 different regions to match varying ambient temperatures.
Road gradient	Gradient categories range from -6° to +6°, with intervals of 2°. VEPM is run for each gradient increment. For light duty petrol vehicles, emission factors for gradients other than 0% are only available for CO and NO_x. For light duty diesel vehicles, emission factors are only available for CO, NO_x and PM. This means that when the model is run for light duty vehicles, the outputs for HC and CO_2 will be for 0% gradient.

	Year	Speed Car	Speed LCV	Speed HCV	Speed Bus	PM B&T size	Avg trip length km	Amb temp °C	Petrol type 0to 6	Diesel type 0to 5	Cold start? yes/no	Degradation? yes/no	% Cats old car 0-100%	% Cats new 0-100%	% Grade -6to 6%	% Load 0-100%
Run	Year	Speed_Car	Speed_LCV	Speed_HCV	Speed_Bus	PMBT_size	AvgTripKm	AmbTemp	PetrolType	DieselType	ColdStart	Degradation	Cats_old_car	Cats_new	Gradient	Load
1	2019	10	10	10	10	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
2	2019	11	11	11	11	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
3	2019	12	12	12	12	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
4	2019	13	13	13	13	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
5	2019	14	14	14	14	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
6	2019	15	15	15	15	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
7	2019	16	16	16	16	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
8	2019	17	17	17	17	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
9	2019	18	18	18	18	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
10	2019	19	19	19	19	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
11	2019	20	20	20	20	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
12	2019	21	21	21	21	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
13	2019	22	22	22	22	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
14	2019	23	23	23	23	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%
15	2019	24	24	24	24	PM10	9.1	15.4	6	5	1	1	15%	0%	-6%	50%

Figure 2.2: Example bulk work input worksheet varying speed (10-100 km/h). Not shown is varying year, road gradient and ambient temperature in the relevant column

2.2.3 Calculating emission factors

VEPM calculates total emission factors for each vehicle category (Table 2.2). The formula for the calculation is shown in Table 2.3. Emission factors for each vehicle category are calculated from the percentage VKT of each vehicle class in the fleet taking into account the proportions of old and new vehicles, and country of manufacture. These emission factors are aggregated into fleet weighted emission factors for light and heavy vehicles depending on the fleet composition as a percentage VKT.

Table 2.2: Vehicle class categories in VEPM

Vehicle category	Vehicle class
Cars	Petrol cars (<1.4L, 1.4L to 2L, and >2L)
	Diesel cars (<2L and >2L)
	Hybrid cars
	Plug in hybrid cars
	Electric cars
Light commercial vehicles (LCVs)	Petrol LCVs
	Diesel LCVs
Buses	NZ fleet data (3.5 – 12t, and >12t)
Heavy commercial vehicles	Diesel HCVs
	Electric HCVs
	Broken down by gross vehicle weight depending on country of origin. Each vehicle weight has default number of axles depending on rigid and articulated trucks.

Table 2.3: Equation 2.1 – total emission factor

Equation	Parameter	Unit	Description
$E = s(m) \times f \times g \times E_{hot} + E_{cold}$	E	g/km	Total emission factor
	s	-	Degradation correction factor for a given accumulated vehicle mileage m
	f	-	Fuel correction factor and is the ratio of emissions for the test fuel compared with a base or reference fuel
	g	-	Gradient correction factor
	E_{hot}	g/km	Hot running emissions factor
	E_{cold}	g/km	Cold emissions contribution to E (function of trip duration and ambient temperature)

2.2.4 Model outputs

For use in the VEMT, bulk excel-based lookup tables are generated from VEPM. These tables detail light and heavy vehicle fleet weighted emission factors for CO, CO_2, NO_x, NO_2, $PM_{2.5}$ exhaust and PM_{BT} for every combination of speed, regional ambient annual temperature, and road gradient. PM_{10} is calculated as the sum of $PM_{2.5}$ and PM_{BT}.

2.2.5 Validation of VEPM

2.2.5.1 New Zealand vehicle emissions factors database

Auckland University has undertaken emission testing on different vehicles to produce thousands of different emission factors. These factors have been collated into a single database(see footnote 4).

The database is made up of predominantly vehicles older than model year 2000, and only samples a small number of diesel vehicles. However, there is still a sufficient amount of emission factors to be able to make valid comparisons between the New Zealand test results and VEPM predictions.

Overall, comparison of the database results with VEPM emission factors for light duty petrol vehicles shows that:

- in general, the VEPM emission factors agree reasonably well with the database results for CO and HC
- for NO_X emissions, there is some discrepancy between the database results and the VEPM emission factors. For some vehicle classes there is not good agreement between the average emission factors from VEPM and the results in the database for NO_X and in some cases the emission-speed trends are different
- there is generally very good agreement between the database and the VEPM results for fuel consumption.

While the sample size was small for the diesel vehicles, there was reasonable correlation between VEPM predictions and the test results.

2.2.5.2 Validation of trends between VEPM and measured on-road vehicle emissions

Research has been undertaken to compare the trends predicted in VEPM with real-world emission trends observed in Auckland remote sensing campaigns. Remote sensing samples the actual exhaust emissions of a large number of real-world vehicles in an on-road situation. Remote sensing has limitations and cannot replace dynamometer drive cycle testing. However, it does provide complimentary information that can be used to check and validate findings derived from a smaller number of drive cycle tests.

This project used remote sensing results from 2003, 2005, 2009 and 2011. The trends in measured CO, nitrogen oxide (NO), HC and uvSmoke (as an indicator of particulate matter) emissions were compared with the trends in predicted CO, NO_X, HC and particulate matter (PM_{10}) emission factors.

The analysis found good agreement between fleet average trends predicted by VEPM and measured trends in average vehicle emissions for the light duty fleet overall between 2003 and 2011. However, when the results were broken down by vehicle type, there were two key exceptions:

- The trend in measured NO emissions (increasing) is contrary to the trend in predicted NO_X emission factors (reducing) from diesel vehicles
- The measured reduction in uvSmoke emissions is less than the predicted reduction in PM_{10} emissions factors, especially for diesel vehicles.

The results suggest that the actual rate of reduction in NO_X and PM_{10} emissions from diesel vehicles is likely to be less than the theoretical rate of reduction predicted by VEPM.

This trend has subsequently been observed in recent studies in New Zealand using portable emissions monitoring systems (PEMS)[5]. In 2018, emissions from a sample of 32 vehicles representative of the New Zealand fleet were measured using PEMS technology. These vehicles comprised of light duty petrol and diesel vehicles, heavy duty diesel vehicles, and manufacturing years from 1996 – 2014 with both New Zealand new and Japanese imports.

In this study, real world NO_x emissions were generally higher than emission standards, and there was little improvement in real world NO_x emissions with improving emissions standards. However, real world $PM_{2.5}$ emissions for light duty vehicles were similar to regulated emissions standards.

When PEMS emission factors were compared to VEPM, differences were seen for all vehicle classes and speeds. This is not unexpected due to the differences between real world emissions and an average speed emissions model. VEPM overestimates the reduction in emissions when they travel downhill, but does a reasonable job for uphill gradients. VEPM tends to underestimate cold start emissions for the first 3 km of the trip for the vehicles tested.

2.3 Geospatial VEMT model inputs

2.3.1 Model inputs

Four datasets are used as inputs to the VEMT; three road centre lines, two supplied by Core Logic and the other Abley, and a national Digital Elevation Model (DEM) derived from Land Information New Zealand (LINZ) topographic data. These datasets provide relevant road attribute data for each roadway in New Zealand and allows variation of emissions to represent road conditions.

The inputs are summarised in Table 2.4. This information has been obtained from different data sources and are merged together to from a cohesive dataset (Section 2.3.2).

Table 2.4: Geospatial input data for VEMT

Parameter	Source	Database field	Notes
Traffic count	Core Logic	TrafficVolume	It represents the annual average daily traffic (AADT) count of a particular road section.

[5] *Testing New Zealand vehicles to measure real-world fuel use and exhaust emissions (2019),* NZ Transport Agency research report

Parameter	Source	Database field	Notes
Fleet profile	Core Logic	hvyVehicleVolume	This represents the average daily traffic count for heavy vehicles of a particular road section and is used in conjunction with TrafficVolume to calculate the light/heavy vehicle ratio.
Speed	Abley	freeflow speed	This represents travel speed data taken from Tom Tom GPS data. If the vehicle speed is outside of the valid specified range, the model will calculate emissions based on the closest valid speed (ie if a vehicle speed is defined as 110 km/h, the model will calculate emissions at 100 km/h).
Gradient	LINZ	*Derived*	This is a raster dataset that has an elevation value every 25 m. The road centrelines are overlaid this elevation surface to derive the gradient of a particular 50 m road section.
Territorial Local Authority (TLA) boundaries	Statistics NZ	Region	These boundaries are used to divide the processing into TLA areas (ie regional council and unitary authorities). This is to ease processing and allow regional variations in annual average ambient temperature.

2.3.2 Merging inputs

Core Logic provides a routable road centreline that includes speed information. They also have an ongoing contract to supply Waka Kotahi, and the TLAs, with another road centreline dataset that combines Waka Kotahi RAMM centreline data, and spatially aligns it to the Core Logic dataset.

While the two centrelines have been spatially aligned, the features themselves often have different start and end points. This is because they have two separate uses; one is a routable network while the other is an asset database.

Abley also provide a road centreline dataset that includes speed information. This dataset is the Safer Journeys dataset used in the Mega Maps platform. The project team has determined that this dataset provides a more realistic speed for the purposes of this project than the Core Logic dataset. Therefore, the Abley dataset has been used as the main source of speed data. When transferring the speed data from the Abley dataset to the Core Logic and RAMM Centreline (which contains the traffic counts and the fleet profile data), care has to be taken to identify all the individual road sections that overlap, and then use a weighted mean calculation to find the speed based on the length of the overlap. This forms the final merged dataset.

In instances where a speed cannot be obtained from the Abley dataset, then the same process is undertaken using the Core Logic dataset in an attempt to obtain the speed from it. In some cases, no speed can be obtained from either and in these cases the road is removed from further processing. These roads are predominantly small rural roads and lanes, and represent approximately 3% of the total number roads.

2.4 Calculating emissions in VEMT

The merged dataset is overlaid over the DEM model to determine road gradients. It has been assumed that all roads are two-way to reduce the amount of manual intervention that would be required when the road networks are updated. The roads are split in to 50 m lengths, and each individual 50 m road length receives a gradient.

Subsequently, each 50 m length of road section then has a speed and a gradient that can be looked up in the relevant VEPM emission table. Processing (including VEPM tables) is split into

TLA areas to account for variances in annual average ambient temperature. VEMT uses a combination of the speeds, ratio of light to heavy vehicles, and the gradient category to determine the pollutant emission factors to apply to each road section.

The relative light to heavy vehicle ratio is multiplied by the appropriate road dependent emission factor to get light and heavy vehicle emissions (g/km/day) for each road section. These are summed together to obtain the combined emission rate (g/km/day) for each road section. The PM_{10} emission rate is calculated by adding together to $PM_{2.5}$ and PM_{BT} emission rates. This process is shown schematically in Figure 2.3.

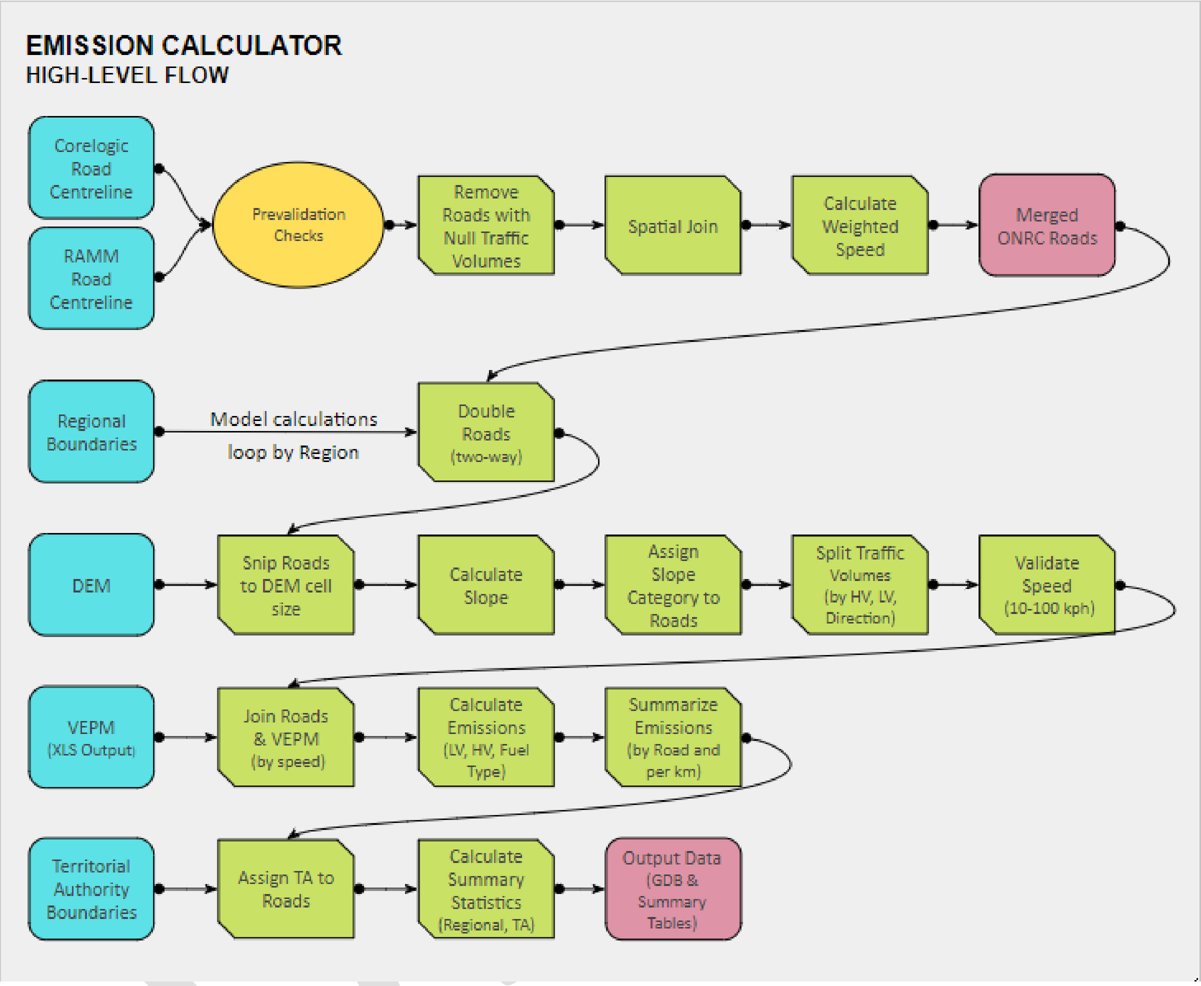

Figure 2.3: Schematic showing calculation steps of emissions in the VEMT

The above steps take place in workflows created using the Feature Manipulation Engine (FME) software to allow automation of the process involved in calculating the emissions. As well as the workflow being flexible and repeatable, it is a graphical tool that illustrates and documents the processing taking place.

The calculation process has been split into two separate FME workflows:

1. Combining speed data from the two centreline datasets. The output of this model is the merged dataset.
2. Calculating total emissions for each section of road based on the calculation process above.

The FME workflow is run for past and current vehicle fleet profiles to allow comparison over time.

2.5 Validation of VEMT

2.5.1 Regional emission inventories

The VEMT has been compared to Regional emission inventories for 2016[6]. The relevant information for this report is summarised below.

Regional emission inventories are estimated on a CAU basis within airshed boundaries. The VEMT emissions inventory was clipped to the same CAU boundaries as provided in regional estimates, and total emissions of all pollutants that had data available.

The VEMT emission inventories were mostly within 25% of the regional inventories. The main reason for the differences was attributed to differences in the VKT used between them. The regional inventories used 2013 VKT data compared to VKT data from 2016 in the VEMT emissions. The average percentage difference across pollutants is similar to the differences in VKT.

2.5.2 CO_2 validation

Jacobs (2019)[7] compared estimated CO_2 emissions from the VEMT with national CO_2 estimates produced by the Ministry for the Environment (MfE) as part of New Zealand's Greenhouse Gas (GHG) Inventory for 2017[8].

MfE produces an annual greenhouse gas inventory, including national CO_2 emission estimates for various energy use categories. The largest source of CO_2 emissions in the energy sector is from road transportation.

MfE bases the CO_2 estimates on annual liquid fuel sales taken from quarterly surveys conducted by the Ministry of Business, Innovation and Employment (MBIE) with oil companies. An attempt is made to exclude non-road vehicle fuel usage (eg Agriculture/Forestry/Fishing) by reallocating fuel usage into different categories following surveys with 19 other smaller oil companies. There is no guarantee that all non-road fuel usage is excluded from annual estimates.

CO_2 emission factors used in the GHG inventory are provided by Refining New Zealand Ltd and are applied according to gross calorific value of the fuel type.

Compared to the MfE's GHG inventory, the VEMT underestimated annual CO_2 emissions by around 25% (average of 2016 and 2017 inventories).

The main reasons for differences between the two inventories were identified as:

- The speed data used in the VEMT is average speed and does not capture vehicles travelling at lower than the posted speed i.e. real world driving conditions[9]
- Uncertainty over whether the MfE estimates excludes all non-road vehicle usage from the Road Transportation category
- There is a small amount of missing AADT data in the VEMT.

It is likely that the VEMT estimates for harmful air pollutants are also underpredicted because the method does not account for low speed conditions on the network. This validation has not been completed using the updated speed variables now included in the VEMT.

[6] *National Vehicle Emissions Mapping, Extended comparison against 2016 Emission Inventories (2016),* Jacobs
[7] *National Vehicle Emissions Mapping, Validation of National Vehicle Emission Dataset CO_2 Estimates (2019)*, Jacobs
[8] https://www.mfe.govt.nz/publications/climate-change/new-zealands-greenhouse-gas-inventory-1990-2017
[9] This study was based on Core Logic speed data not Abley which is the preferred VEMT dataset

3 CONCENTRATION CALCULATOR

3.1 Introduction

Emission factors from VEMT are converted to nearside road concentrations using the algorithm developed as part of the Design Manual for Roads and Bridges (DMRB algorithm) Air quality Screening Model[10]. A high-level flow of the concentration calculator is shown in Figure 3.1.

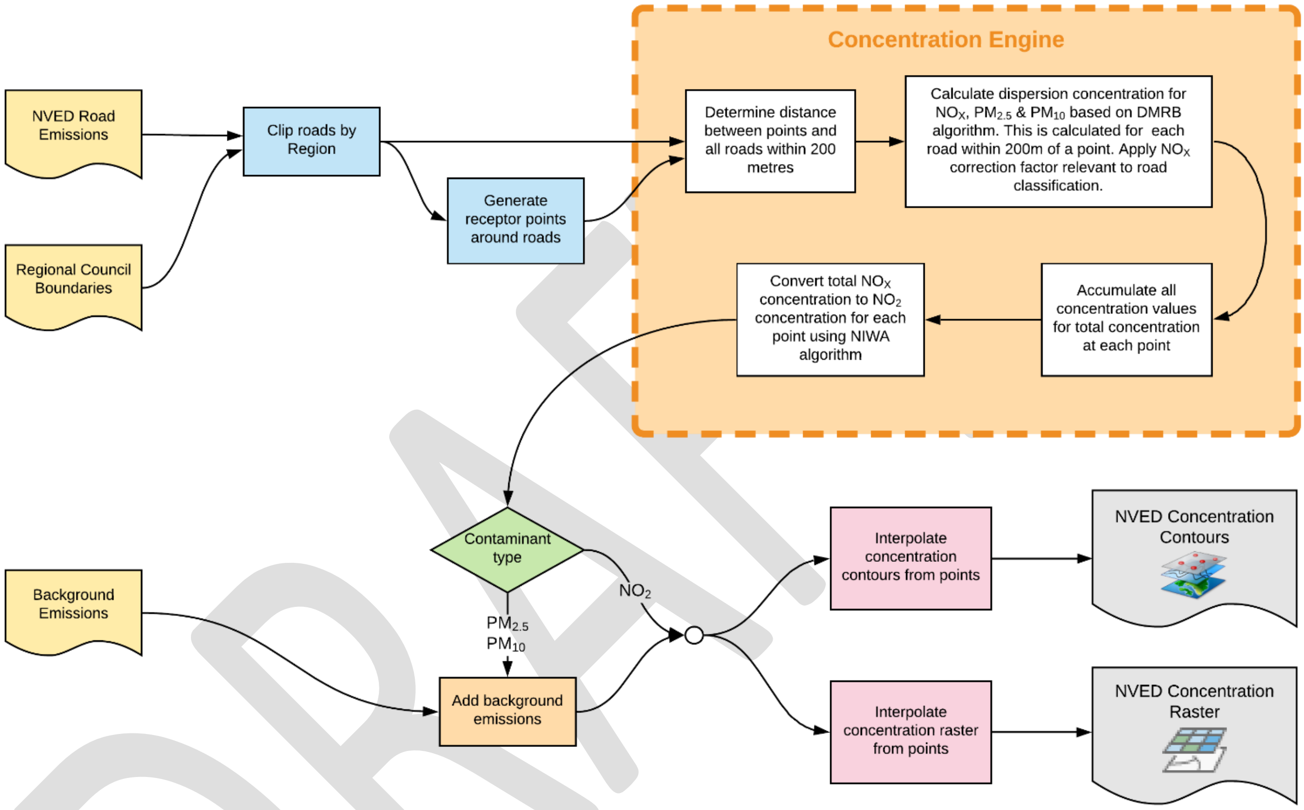

Figure 3.1: Schematic showing calculation stages of the concentration calculator

3.2 DMRB algorithm

The DMRB algorithm calculates pollutant concentrations dependent on distance from the centre of the road. The dispersion algorithm assumes average meteorological conditions and does not consider local variations.

The concentration calculator is housed in a GIS system to allow determination of receptor point distances from roads within 200 m. A network of receptor point locations is assigned at various distances from each road centreline to allow calculation of concentrations along each road. At each receptor location, the contribution from all roads within 200 m are summed to provide the concentrations at each location. The contribution to total pollutant concentration will depend on distance from the road.

The DMRB algorithm is used to calculate annual NO_x, $PM_{2.5}$, and PM_{10} concentrations near to roads. Depending on the contaminant (NO_x or PM), they are treated differently within the model. Once concentrations at each receptor are calculated, they are interpolated to concentration contours.

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[10] *Design Manual for Roads and Bridges, Volume 11, Section 3 Environmental Assessment Techniques, Part 1 HA207/07 Air quality (2007),* The Highways Agency

Discussed further in Section 3.3, total NO_x at each receptor location is adjusted depending on the adjacent road classification. Total NO_x is converted to NO_2 using the National Institute of Water and Atmospheric Research (NIWA) conversion method and interpolated to concentration contours. Given that the major source of NO_x and NO_2 is transport related emissions, near roadside concentrations will be dominated by output from the DMRB so to avoid double counting, background concentrations are not applied unless predicted concentrations fall below background levels.

For $PM_{2.5}$ and PM_{10} predicted concentrations, no adjustment is applied as there is insufficient data to understand how representative it is of monitored roadside concentrations. Concentrations of particulate matter will be dominated by other sources than road transport (ie domestic heating sources) so background concentrations are added to the predicted DMRB concentrations to represent total near roadside concentrations (Section 3.5).

3.3 DMRB validation and NO_x adjustment

The DMRB model was validated using monitored NO_2 concentrations from the Waka Kotahi passive sampling network[11]. Monitoring sites were selected to be representative of sites dominated by transport related emissions, and modelled output was compared to these monitored concentrations.

The ratio of modelled road source contributions (the DMRB output) to monitored road source contributions can provide adjustment factors to improve the accuracy of the model at reproducing roadside concentrations.

Monitored NO_2 was converted to NO_x using the NIWA NO_x/NO_2 conversion method[12] and compared with DMRB output at the monitor locations (Figure 3.2). The model tended to overestimate monitored roadside concentrations.

It was investigated whether different road types based on their One Network Road Classification (ONRC) performed differently in the model. Only monitoring locations on National & High Volume, and Regional & Arterial were available in the assessment. It was found that the model performs better as the traffic volume decreases on roads.

Given the definition for identifying roadside monitoring locations, no monitoring data was available for Low Volume & Access road ONRC categories. Not allowing for an adjustment on these lower volume roads could lead to higher-than-expected concentrations in some urban areas on lower volume roads adjacent to higher volume roads. Therefore, in the absence of a method and data to develop a specific adjustment factor, Low Volume & Access roads are conservatively considered in the same category as Regional & Arterial roads.

At each location, the following model adjustments are applied to total NO_x depending on the adjacent road classification, and then converted to NO_2 using the NIWA conversion method:

- National & Arterial: 0.53
- All other road types: 0.64

[11] *Nitrogen Oxides DMRB model verification (2020),* Tonkin & Taylor Ltd, Letter. Note, the passive monitored NO_2 concentrations have not been bias corrected in relation to reference methods.
[12] *Review of NO2/NOx empirical conversation equations (2019)*, Longley I. and Sommervell E., NIWA

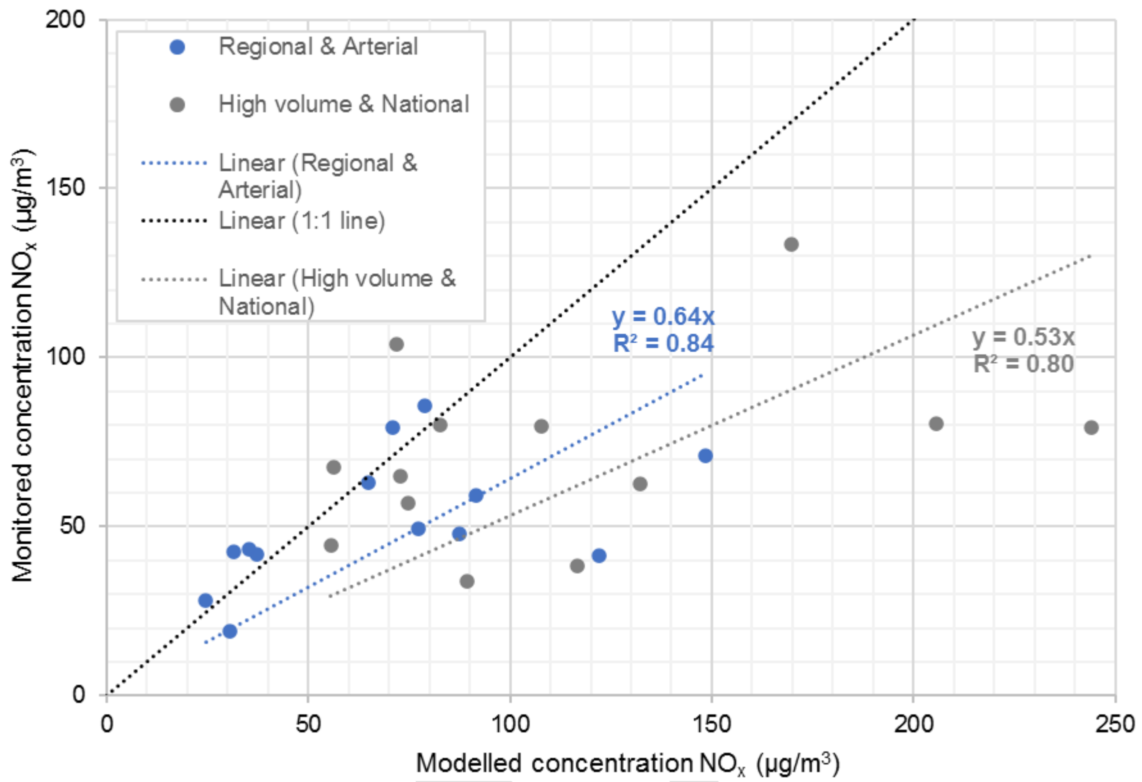

Figure 3.2: Correlation of modelled to monitored annual NO_x concentrations at roadside locations showing comparison with the 1:1 line

3.4 Background NO_2 concentrations

3.4.1 Introduction

A full description of background NO_2 concentrations is in *'Background Annual Average Nitrogen Dioxide Concentrations'*[13]. The background concentration is incorporated in all locations where predicted roadside contributions from the DMRB algorithm fall below the background.

3.4.2 Method

Representative background monitoring data has been used as a priority where available, including historic data, except where concentrations are above 20 µg/m³ as this is considered too high to be true background.

For CAUs where monitoring data is not available, two methods have been used to determine representative background concentrations:

1. A modelled dataset has been used based on the NIWA Traffic Impact Model (TIM) (the NIWA TIM model)

2. Default representative rural and urban township concentrations assumed based on urban or rural classifications.

The NIWA TIM model was developed to estimate long term exposure to transport related NO_2 concentrations. It also estimated long term background concentrations across the country aggregated to CAU level. A roadside concentration buffer was created around every road and the roadside impacts (within the buffer) were subtracted from the concentration raster. The concentrations in each CAU are aggregated, and the mean value gives the estimated background concentration in the CAU.

[13] *Background Annual Average Nitrogen Dioxide Concentrations (2020)*, Letter report, Tonkin & Taylor Ltd

The NIWA TIM concentration has been assumed in all CAUs where available, with exception of:

- CAUs where concentrations are greater than 20 µg/m^3 as this is too high to be considered a true background. In these instances, representative concentrations from adjacent CAUs have been identified and adopted
- Where concentrations are less than the assumed default rural or urban background township background. In these cases, the default values have been used (see below).

For CAUs where no monitoring or NIWA TIM data was available, two methods have been used based on urban and rural classifications:

- A rural township (urban) background concentration of 4.5 µg/m^3 has been assigned based on average data from monitored and NIWA TIM in similar CAUs
- A default rural background concentration of 3.0 µg/m^3 has been adopted based on the mean concentration from annual average monitoring data over 3 years (2017 to 2019) at a rural site in Patamuhoe (southwest of Auckland).

3.4.3 Validation

NIWA TIM has been evaluated against measured data at the urban background monitoring sites (Figure 3.3). The NIWA TIM has moderately good predictability with expected concentrations. As the NIWA TIM is a traffic impact model, it will underpredict concentrations where there are other sources of NO_2 or, local terrain or meteorological effects.

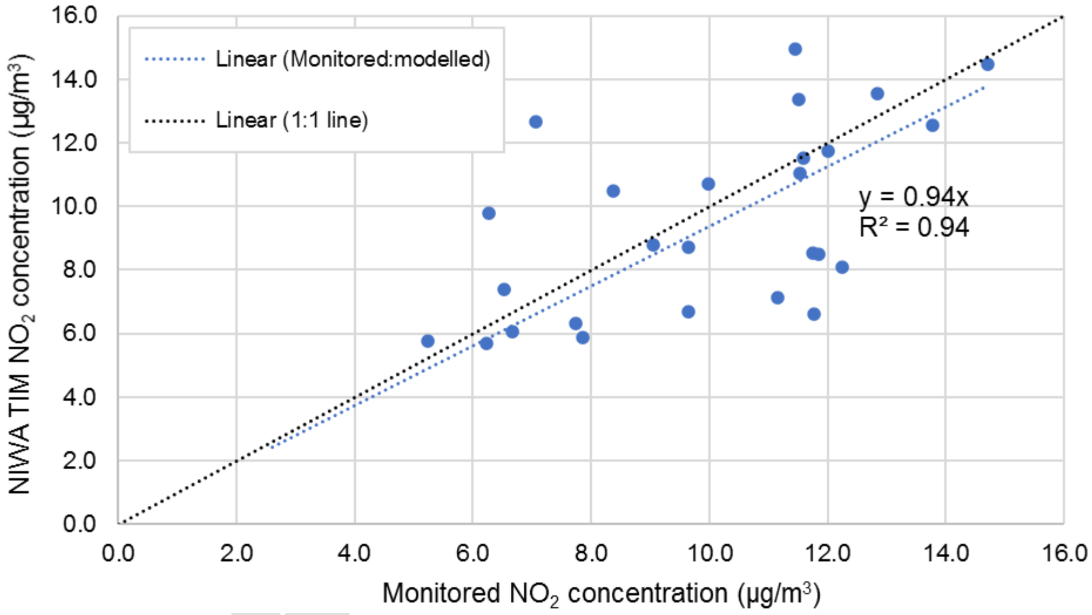

Figure 3.3: Comparison of monitored versus modelled annual average NO_2 concentrations at urban background monitoring sites, and showing a 1:1 line (black) and linear correlations (blue)

3.5 Background $PM_{2.5}$ and PM_{10} concentrations

3.5.1 Introduction

A full description of background 24-hour $PM_{2.5}$ and annual $PM_{2.5}$ and PM_{10} concentrations is included in '*Particulate Matter Background Air Quality Maps*'[14]. The background is added to PM_{10} and $PM_{2.5}$ concentrations output from the DMRB algorithm.

[14] *Particulate Matter Background Air Quality Maps, Summary of Methodology (2020)*, Tonkin & Taylor Ltd

3.5.2 Method

The background concentrations are developed from a combination of modelled and monitored data. The dataset is based on a model developed by NIWA (the 'NIWA model')[15] to calculate exposure to $PM_{2.5}$ and PM_{10} in each CAU.

Although the background dataset largely followed the same method as the NIWA model, it is based on longer-term average monitored data (where available) to represent current conditions (mean of 2017-2019 annual average concentrations).

Annual average $PM_{2.5}$ is calculated by estimating the natural and anthropogenic contributions to sum to a total concentration.

Natural (non-anthropogenic) contributions to $PM_{2.5}$, PM_{coarse} and PM_{10} are calculated as follows:

- The natural $PM_{2.5}$ concentration is the sum of a modelled marine aerosol component, based on the distance from the east or west coast, and a fixed soil and sulphate contribution of 1.4 µg/m^3;
- The natural PM_{coarse} concentration is the sum of a modelled marine aerosol component and a dust component of 3 µg/m^3 for Otago and Canterbury, and 1 µg/m^3 for every other region; and
- The natural PM_{10} concentration is the sum of natural PM_{coarse} and natural $PM_{2.5}$.

The anthropogenic component of $PM_{2.5}$ is calculated using the following methods (in order of priority):

- Subtracting the modelled natural $PM_{2.5}$ component from $PM_{2.5}$ observations where available (mean of 2017-2019 annual averages); or
- Where PM_{10} observations (but not $PM_{2.5}$) are available:
  - Estimating total PM_{coarse} by adding the modelled natural PM_{coarse} component and a modelled urban PM_{coarse} component based on a relationship with traffic (vehicle kilometres travelled); and
  - Subtracting the modelled PM_{coarse} and natural $PM_{2.5}$ from the PM_{10} observations (mean of 2017-2019 annual averages or the most recent available annual average data); or
- Using the same method but substituting default $PM_{2.5}$ concentration values based on the HAPINZ rural and urban classification codes for $PM_{2.5}$ observations.

The anthropogenic component of PM_{10} is calculated by subtracting the modelled natural PM_{10} component from observed long-term annual average concentrations or, where PM_{10} observations are not available, from default PM_{10} concentration values based on the HAPINZ[16] rural and urban classification codes.

24-hour $PM_{2.5}$ concentrations are calculated to represent the 4th highest daily concentration. This is to represent peak 24-hour concentrations whilst removing the extreme values. Where monitored data is available, the 4th highest 24-hour average concentration is used as a priority. In all other locations. a correlation of monitored annual to 4th highest 24-hour data is used to predict background 24-hour concentrations.

3.5.3 Validation

The model was validated by comparing NIWA modelled PM_{coarse} to monitored concentrations (monitored PM_{10} – $PM_{2.5}$) (Figure 3.4). The model tends to overestimate PM_{coarse} compared to observations. This means that where annual $PM_{2.5}$ concentrations are estimated from observed PM_{10} concentrations, the $PM_{2.5}$ is likely to be underestimated.

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[15] *PM2.5 in New Zealand - Modelling the current levels of fine particulate air pollution (2019),* Longley I. and Coulson G., NIWA

[16] *Health and air Pollution in New Zealand (HAPiNZ) Main Report (2007),* Fisher G., Kjellstrom K., Kingham S., Hales S. and Shrestha R.

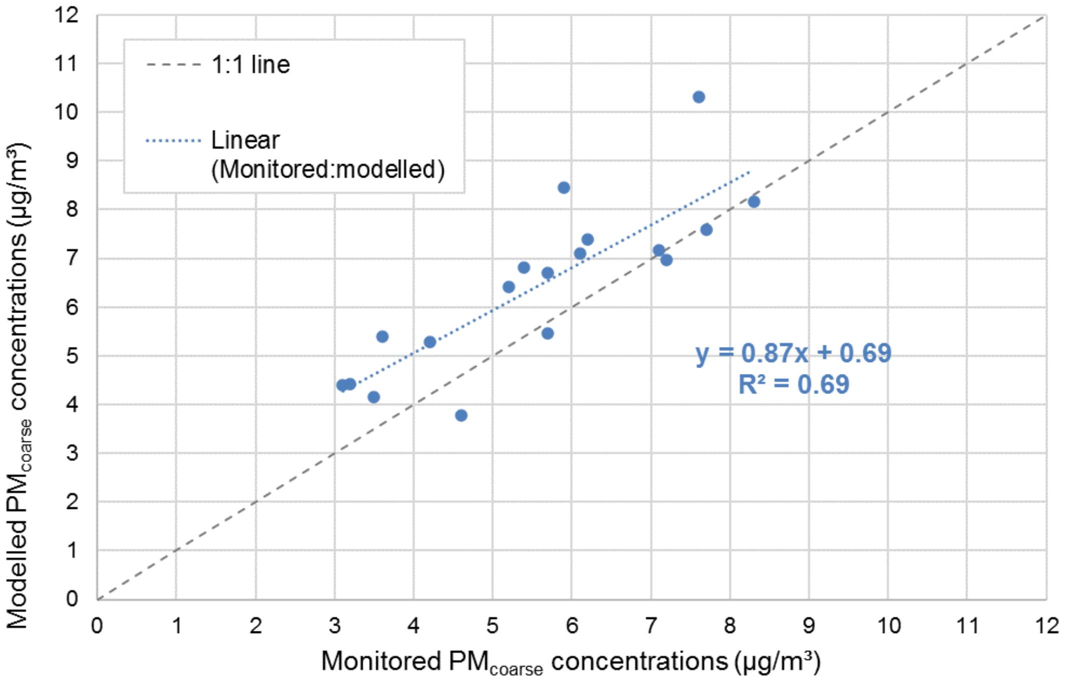

Figure 3.4: Comparison of monitored and NIWA modelled PM_{coarse} concentrations

4 EXPOSURE CALCULATOR

4.1 Introduction

The exposure calculator uses contaminant concentration estimates for road links in New Zealand and StatsNZ population data to estimate the total population exposed to pollutants from road transport.

The concentration is expressed as contours and the population living within a concentration contour that is greater than 75% of the relevant air quality guideline is deemed as being exposed to ‘elevated’ pollutant concentrations.

4.2 Method

The outputs of the concentration calculator and the dwelling estimator are used to calculate exposure. The exposure calculator is an FME model that determines the number of dwellings and people living inside an exceedance zone (Figure 4.1).

The model can be run for NO_2, $PM_{2.5}$ and PM_{10}. For each pollutant an exceedance limit is set as concentrations higher than 75% and 100% of the relevant guideline:

- 15 µg/m^3 of the 20 µg/m^3 annual average PM_{10} guideline from the Ambient Air Quality Guidelines (AAQG)
- 7.5 µg/m^3 of the 10 µg/m^3 annual average $PM_{2.5}$ concentration in the current World Health Organization (WHO) guidelines and proposed amendment to the National Environmental Standards for Air Quality (NESAQ)
- 30 µg/m^3 of the 40 µg/m^3 annual average WHO NO_2 guideline.

The concentration contour matching this limit is selected and then converted into a closed shape and output as an exceedance zone dataset. All dwellings that intersect or are within this exceedance zone are then selected and output as a dwelling exposure dataset. The populations in the exposed dwellings are summarised by region and output to a spreadsheet.

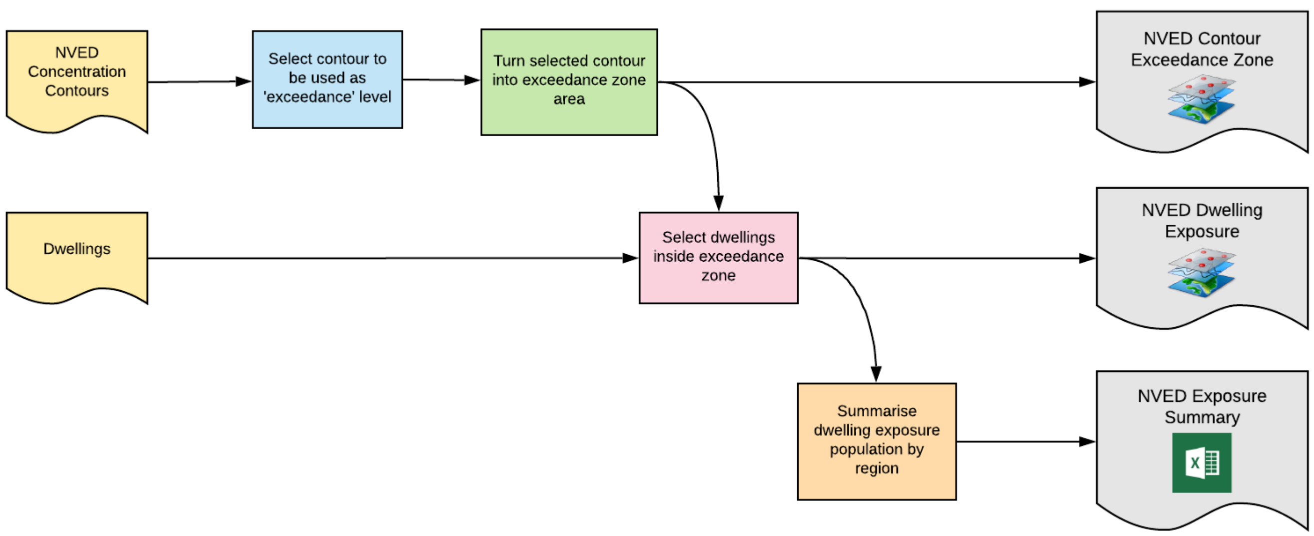

Figure 4.1: Schematic showing the overall calculation for population exposure, the concentration calculator (contours) and dwelling estimator are discussed further in Section 3 and 4.3, respectively

4.3 Dwelling estimator

LINZ produce a Building Outline dataset which provides current outlines within mainland New Zealand captured from aerial imagery. This dataset is regularly maintained when new aerial imagery is available and is the best building dataset available in New Zealand. However, with the nature of new building development, it is prone to becoming out of date quickly. This dataset also does not distinguish between different types of buildings, ie between houses, sheds, warehouses etc. Therefore, by itself it cannot be used as a residential dwelling dataset.

The dwelling estimator is an FME model that attempts to refine the LINZ dataset to more closely reflect residential dwellings. It does this in two steps:

1. The first step uses the calculated floor area of each building. The model removes buildings that might be considered sheds or garages (< 80 m^2), and buildings that might be considered too large for residential buildings (> 800 m^2).
2. The second step uses the LINZ cadastral data to determine the properties that the buildings fall in and ensures that there is only one building per property. If there are multiple buildings within a property, then the building that is retained is the building that is closest to the LINZ address point.

Once the buildings have been refined, populations are assigned to each one. This is done by using the Statistics NZ meshblocks, and dispersing the meshblock population evenly among all the dwellings that fall within it.

The dwelling estimator is shown schematically in Figure 4.2.

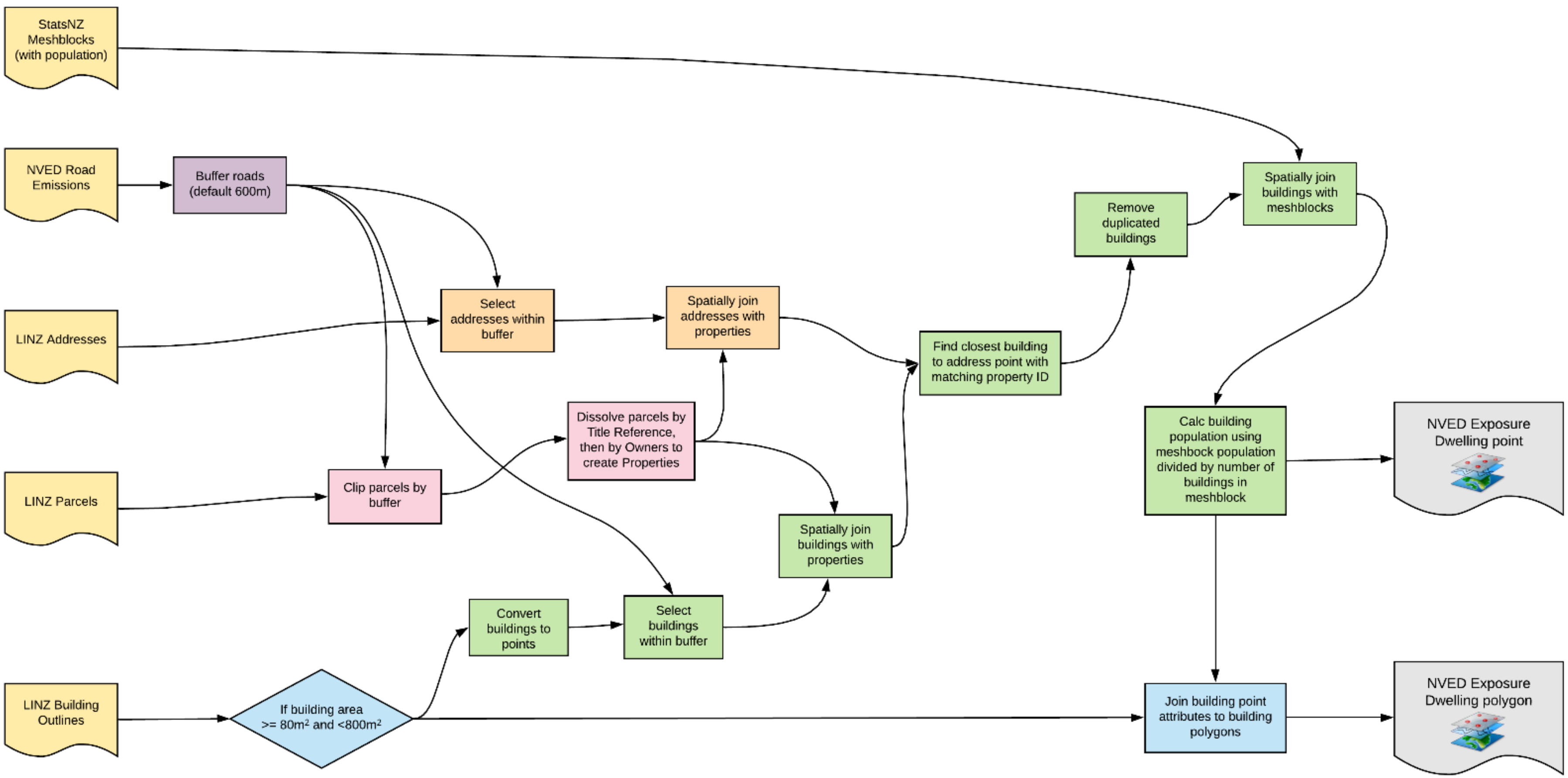

Figure 4.2: Schematic showing the flow diagram of calculation steps for the dwelling estimator

5 LIMITATIONS

The following table describes limitations of different aspects of the VEMT, concentration and exposure calculator. These have been included here for consideration when using the outputs of components discussed in this report.

Table 5.1: Summary of limitations and considerations when using the output of the VEMT, concentration calculator, exposure tool and its subsidiaries

Limitation	Consideration
Average speed model and data	Average speed models aim to be representative of average speed of a vehicle throughout its journey. However, average speed, will not represent variances in speed and resultant emissions during the drive cycle such as acceleration/deceleration and stops/starts. On roads prone to congestion, intersections, or poor road conditions, average speed models may not represent vehicle emissions on that section of road. This is also relevant for average speed data from Abley, as this speed will not capture daily variations in speed on the road (eg congestion, intersections, stop/start driving).
Urban centres	Local effects on emissions and dispersion in urban centres will not be captured in the model. Urban centres are more likely to be impacted by congestion and effects of vehicle stop/start and not average speed conditions as discussed above. This will change emission profiles of road vehicles in urban centres. Effects such as street canyoning are likely to significantly alter dispersion of pollutants from road transport and can lead to higher concentrations than predicted through dispersion under the average meteorological conditions described in the DMRB algorithm.
Gaps/errors in traffic data	Gaps and errors in traffic data mean that accurate estimates are not able to be produced for each year of VEMT where there is no available data. Previous years' data can be back-casted with current estimates to fill missing gaps and provide a like-for-like comparison, but roads with missing data will be excluded as there is no method to estimate missing attributes. These roads are predominantly small rural roads and lanes, and represent approximately 3% of the total number of roads.
Road link length	Road links for calculating emissions are split in 50 m sections so that gradient can be applied. While road links smaller than this are included within the VEMT, it does not include the level of granularity to enable lower average speeds to be applied in approaches to junctions.
VEPM particulate emission estimates	VEPM emission estimates only account for exhaust emissions and brake and tyre wear. Emissions of particulate from road surface wear and evaporative emissions are not accounted for.
VEPM emission factors	VEPM emission factors include 'real-world' emission factors from COPERT and New Zealand real world consumption correction factors for diesel, but does not take into account real world in-service vehicle emissions (eg driver behaviour, gross emitters, effects of vehicle tampering). Real world emissions are typically higher.
CO_2 is not $CO_{2\text{-e}}$	The CO_2 estimated from the VEMT represents CO_2 emissions and doesn't include total GHG (expressed as CO_2 equivalent, $CO_{2\text{-e}}$) such as N_2O and CH_4. Carbon reporting in New Zealand is expressed as $CO_{2\text{-e}}$. VEPM will need to be updated to incorporate further GHG emission estimates to meet reporting requirements for GHG from road transport in New Zealand.

Limitation	Consideration
DMRB concentration calculator	DMRB is a screening algorithm that does not incorporate meteorological data, or local terrain or building effects (eg street canyons) that will affect dispersion of traffic related emissions.
Background PM_{10} and $PM_{2.5}$	Background PM_{10} and $PM_{2.5}$ concentrations represent total exposure to these contaminants. Traffic contributions were not removed from model estimates as there was no consistent or practical way to determine traffic contributions in each CAU. This could lead to “double-counting” of transport related PM concentrations when considering predicted DMRB concentrations.
Background NO_2 concentrations	The background concentrations are largely derived from a traffic impact model, so will underpredict concentrations in areas where other sources are present (eg near ports, airports, and some industrial areas), or with local terrain or meteorological effects.
Exposure dwelling calculator	Assumptions in the exposure calculator and dwelling estimator about locations of where people live can lead to limitations in estimating populations exposed to elevated concentrations. The only method to determine dwellings is based on square metreage of dwellings. This could lead to possible exclusions/inclusions of dwellings in each CAU. The highest resolution of population data available is at a meshblock level. Averaging the total meshblock population amongst all dwellings will evenly distribute the population amongst number of dwellings, but not represent the actual population living in a specific dwelling.

6 EXAMPLE OUTPUTS

6.1 Emissions data outputs

6.1.1 Visual data representation

Below shows examples of how emissions data can be represented and summarised on diagrams.

Figure 6.1 shows an example of aggregated CO_2 emissions by region and broken down by light/heavy vehicle ratio.

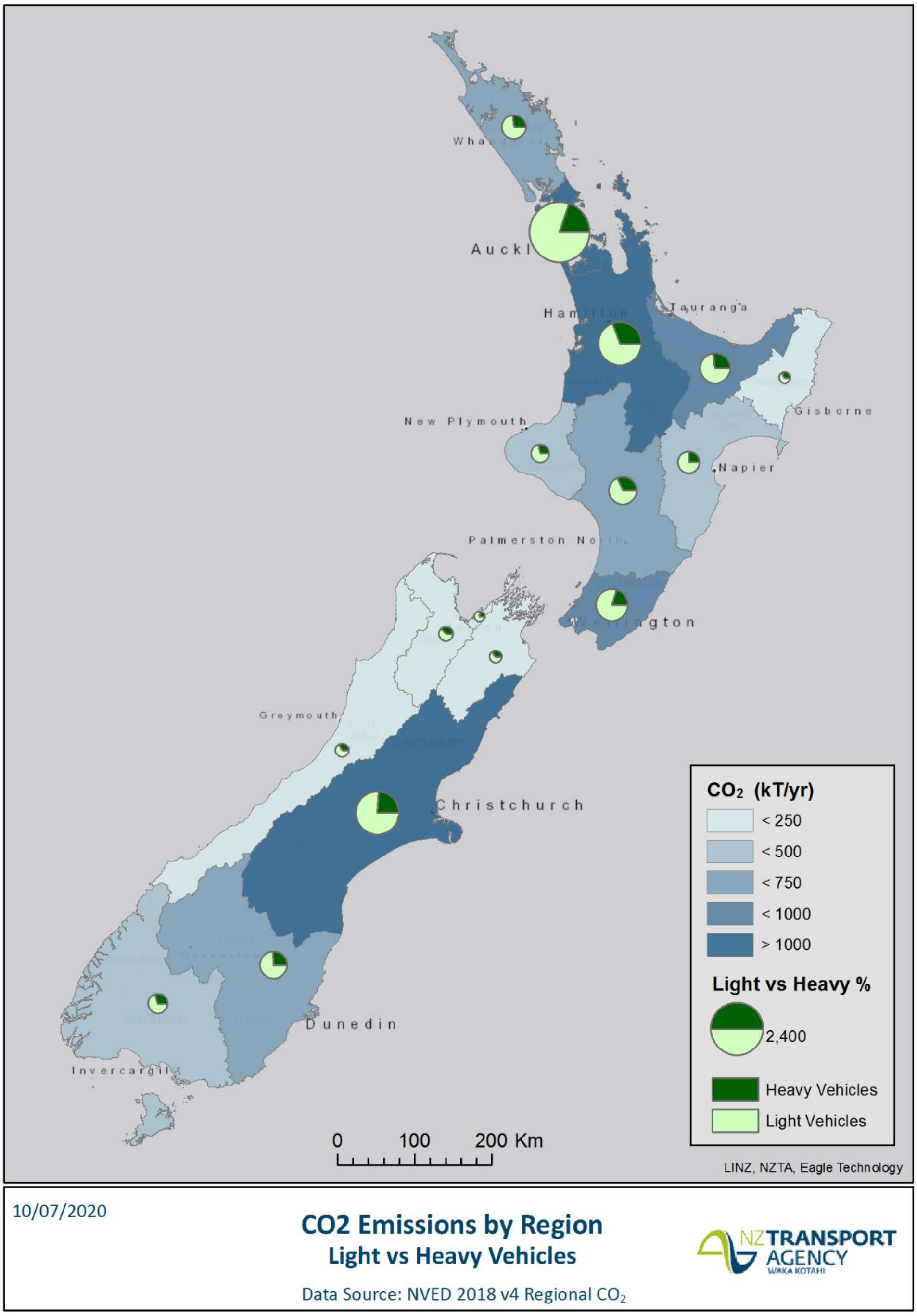

Figure 6.1: Example output of nationwide road transport related CO_2 emissions by region and the corresponding proportion of light to heavy vehicles

Figure 6.2 shows example output of road transport CO_2 emissions by Statistical Area 1 Units (SAU).

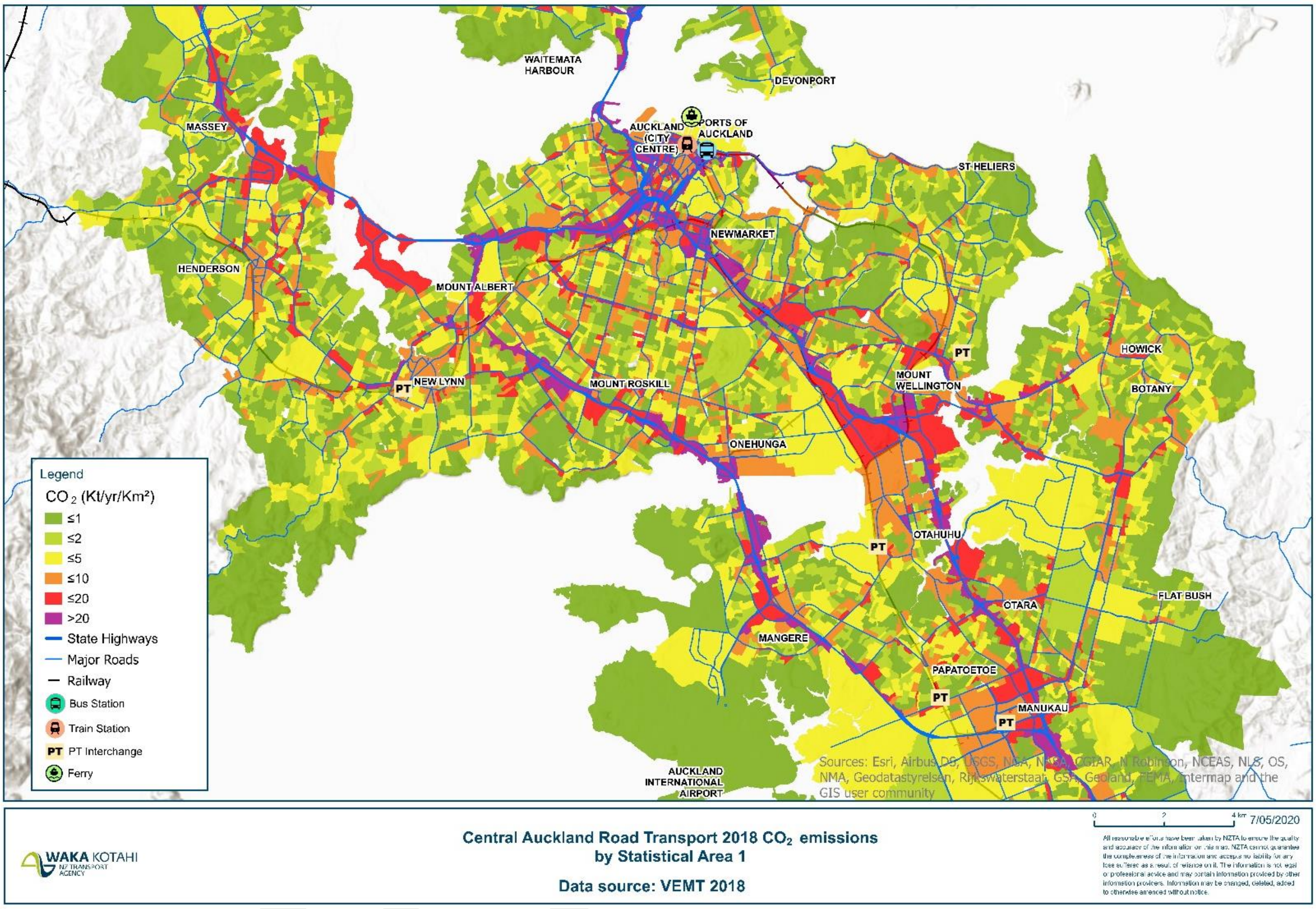

Figure 6.2: Example output of central Auckland road transport CO_2 emissions by Statistical Area 1 units

Figure 6.3 shows regional summaries of CO_2 emissions from light vehicles.

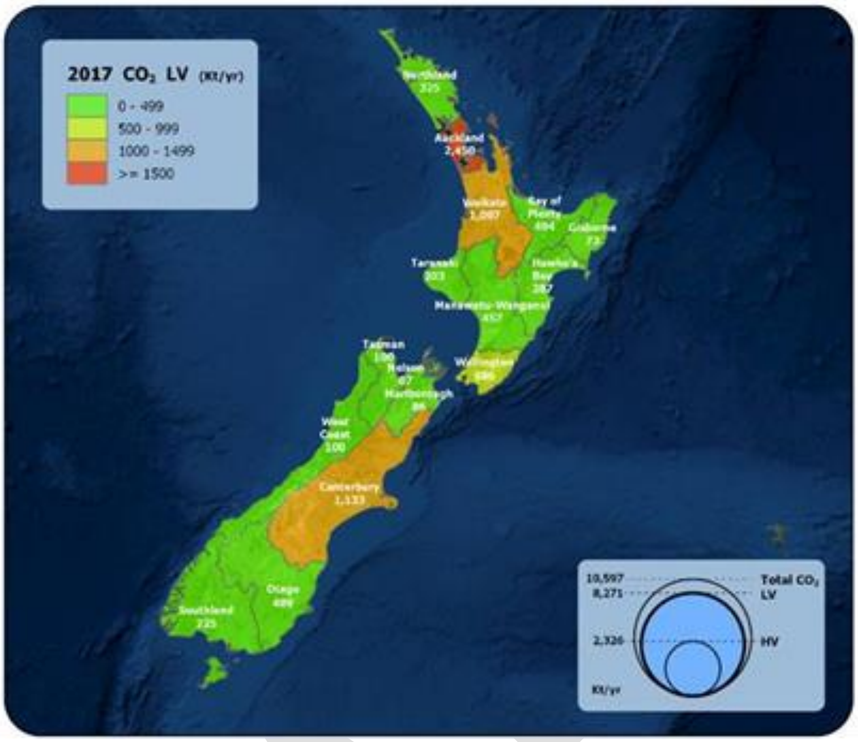

Figure 6.3: Regional summaries of CO_2 emissions from light vehicles in 2017 showing the relative proportion of light to heavy vehicle emissions

6.1.2 Summary tables

Data can also be provided in summary tables at various spatial resolutions including National, regional and by urban area, and by vehicle and fuel type.

Figure 6.4 shows an example excel summary table of total pollutant emissions by region for 2019, and Figure 6.5 shows summaries by urban area for the same year.

		Total					
Region	**VKT** (`000 km/Year)	CO (Tonnes/Year)	CO2 (Tonnes/Year)	NOX (Tonnes/Year)	NO2 (Tonnes/Year)	PM10 (Tonnes/Year)	PM2.5 (Tonnes/Year)
Auckland	13539.0945	27560.50974	3209791.297	10456.86435	1964.354673	674.1938203	398.7427864
Bay of Plenty	3226.742067	7081.344011	796357.794	2729.405981	485.617587	166.8388265	103.3281134
Canterbury	6754.080462	14209.77922	1646541.682	5477.188692	982.9314293	347.3739075	211.3985185
Gisborne	416.2059073	923.9632172	109616.8917	383.8775161	66.11632147	23.09955999	14.32600229
Hawkes Bay	1722.546252	3738.893956	424825.6787	1429.991585	255.6828501	88.270504	53.98218268
Manawatu-Wanganui	2690.154198	6128.24295	693177.3623	2456.929897	423.5479606	145.8108752	95.47641931
Marlborough	513.5510046	1163.552613	139313.5936	511.5786005	85.36588489	30.18538202	19.64717948
Nelson	375.4564393	839.1486893	94409.99341	312.4063525	57.06575326	20.27449628	11.80069031
Northland	2103.187448	4423.348477	520388.7446	1819.532711	324.9506567	110.0062614	69.27782599
Otago	2617.388698	6968.357776	666322.6454	2294.283455	415.6040014	141.7698846	92.33020458
Southland	1342.118176	3007.331519	335986.5887	1172.317221	205.0158777	71.84679402	47.195401
Taranaki	1160.675526	2667.990823	284182.4421	968.0288719	173.7286918	59.47651757	37.64711259
Tasman	640.1609811	1485.62149	168149.7671	602.2291243	102.7813764	35.57660412	22.79678925
Waikato	6625.796449	14789.58802	1682477.904	5973.577748	1033.186513	353.6698939	231.8547136
Wellington	3739.940703	9251.200945	910389.1917	3023.253294	565.8482704	194.0161375	118.9592972
West Coast	596.8344947	1452.997385	149733.8742	528.433183	92.44393734	31.026656	20.58191998
Total	48063.93	105691.87	11831665.45	40139.90	7234.24	2493.44	1549.35

Figure 6.4: Example regional emissions summary table by pollutant for 2019

Name	Population (2018)	VKT (km/day)	CO (T/yr)	CO_LV (T/yr)	CO_HV (T/yr)	CO_P (T/yr)	CO_D (T/yr)
Gisborne	34,527.00	651,332.59	335.86	326.97	8.90	315.07	20.72
Hastings	44,952.00	663,385.75	419.30	409.02	10.29	393.49	25.70
Hibiscus Coast	53,580.00	1,125,586.63	672.99	651.60	21.39	627.28	45.59
Invercargill	47,625.00	841,855.71	612.00	589.61	22.38	569.22	42.65
Napier	62,144.00	1,377,483.93	933.64	891.23	42.41	857.95	75.50
Nelson	48,064.00	958,679.81	700.15	674.35	25.79	649.85	50.16
New Plymouth	53,991.00	1,219,876.49	756.82	740.52	16.30	714.48	42.19
Palmerston North	76,249.00	1,614,783.27	903.24	871.69	31.55	840.12	62.92
Porirua	55,221.00	1,422,935.97	896.12	857.65	38.47	828.69	67.29
Rotorua	54,203.00	850,860.36	570.06	541.48	28.58	521.43	48.50
Upper Hutt	41,307.00	650,283.92	488.53	469.33	19.20	453.39	35.05
Whanganui	39,731.00	695,820.31	409.39	395.85	13.53	381.76	27.54
Whangarei	50,776.00	1,149,122.40	747.24	717.30	29.95	688.92	58.15

Figure 6.5: Example of output excel summary tables in large urban areas by vehicle type for 2019

6.2 GIS outputs

Figure 6.6 shows example output of NO_2 concentration contours in central Auckland.

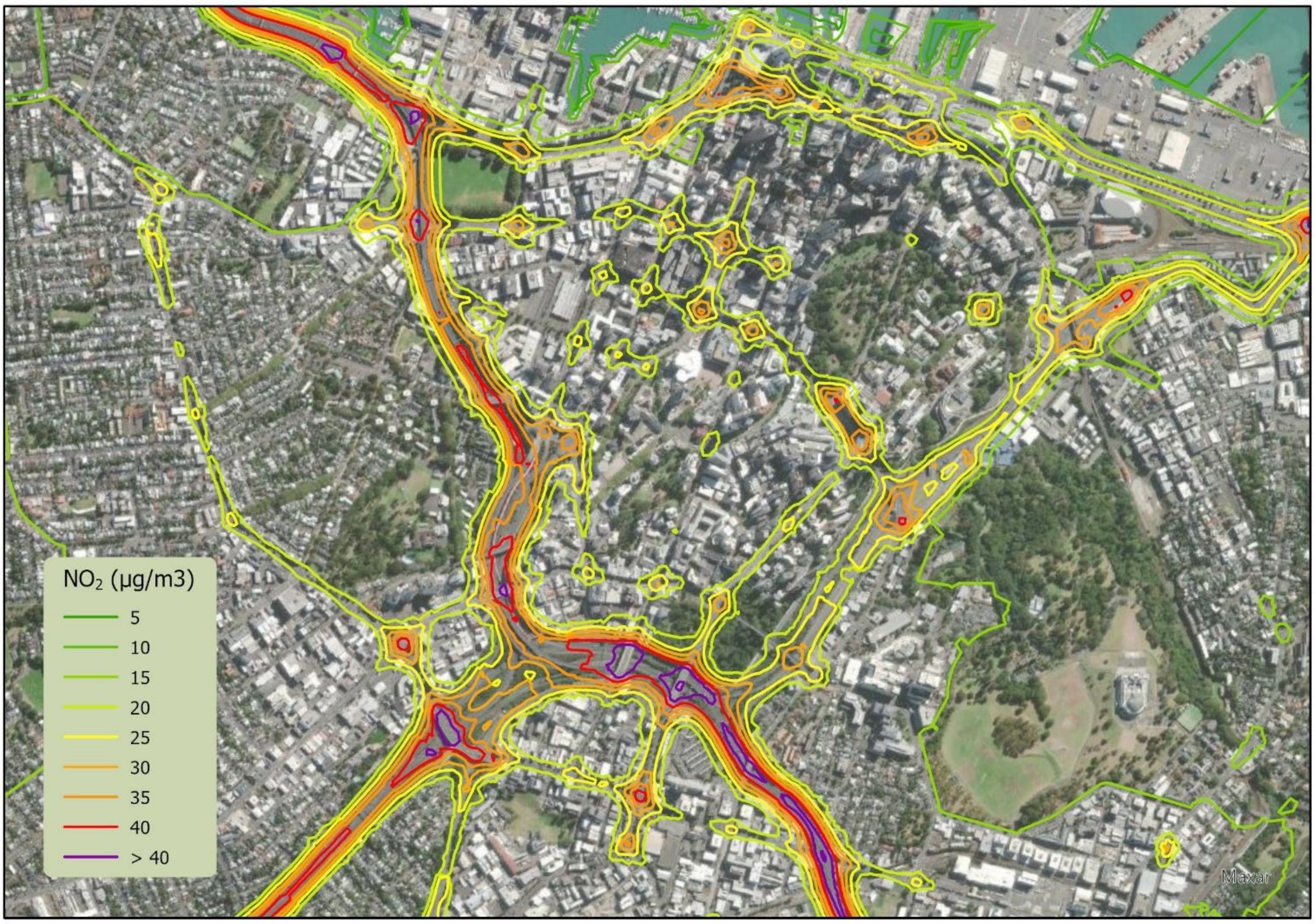

Figure 6.6: Example GIS output showing concentration contours of NO_2 in 5 µg/m^3 increments outputted from the VEMT and concentration calculator

Figure 6.7 shows an example of identified dwellings within the concentration exceedance zone.

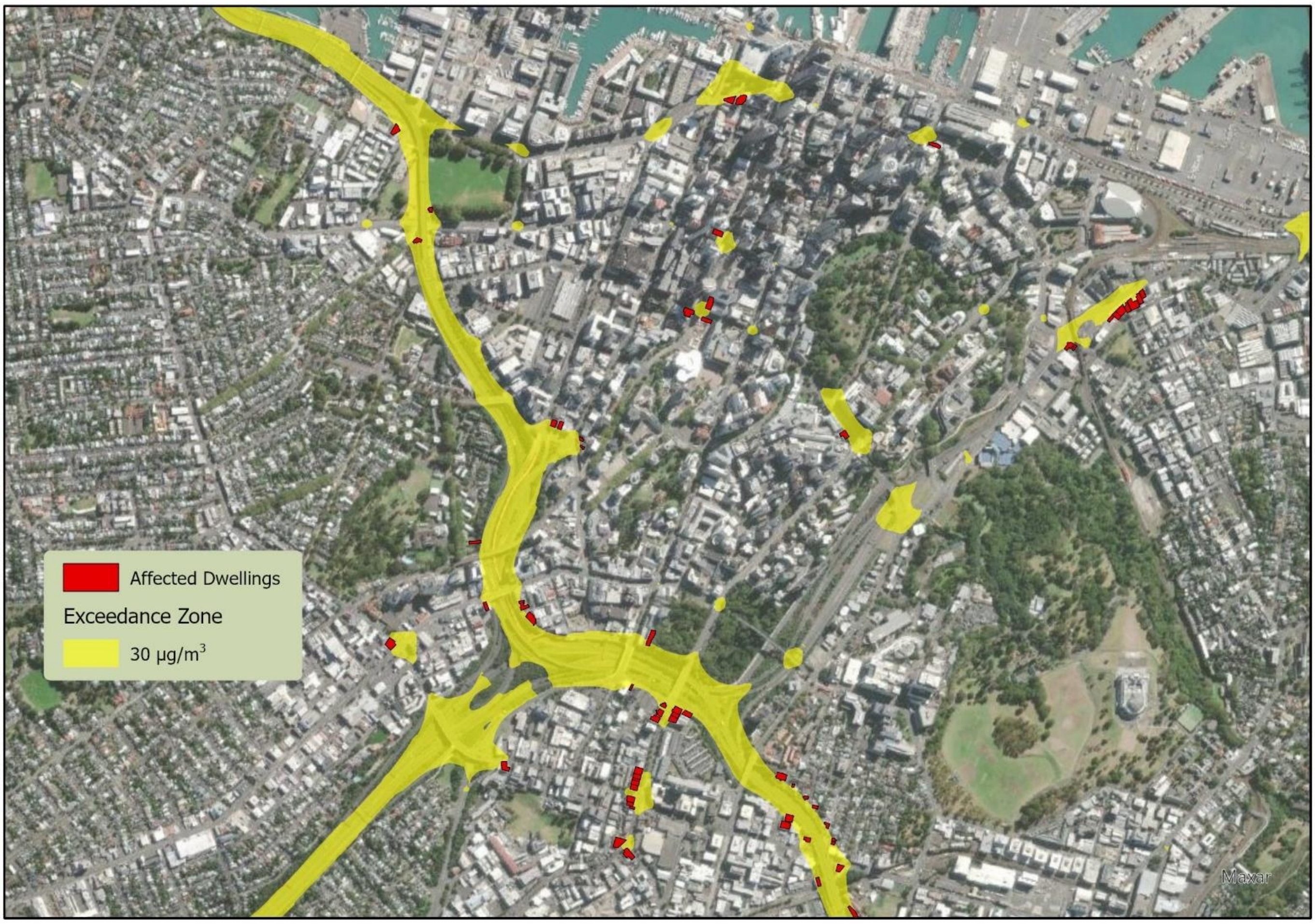

Figure 6.7: Dwellings exposed to the concentrations of NO_2 above the 30 µg/m^3 exceedance limit

APPENDIX A GLOSSARY OF TERMS

Term	Description
AADT	Annual average daily traffic
AAQG	Ambient Air Quality Guidelines
CAU	Census area unit
CO	Carbon monoxide
CO_2	Carbon dioxide
COPERT	Computer Model to Calculate Emissions from Road Transport
DEM	Digital elevation model
DMRB	Design Manual for Roads and Bridges
FME	Feature Manipulation Engine
GHG	Greenhouse gas
GIS	Geospatial information system
HC	Hydrocarbons
HCV	Heavy commercial vehicle
LCVs	Light commercial vehicle
LINZ	Land Information New Zealand
MBIE	Ministry of Business, Innovation and Employment
MfE	Ministry for the Environment
MoT	Ministry of Transport
NESAQ	National Environmental Standards for Air Quality
NIWA	National Institute of Water and Atmospheric Research
NO	Nitrogen Oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides (total nitrogen oxide and nitrogen dioxide)
NVED	National Vehicle Emissions Dataset

Term	Description
ONRC	One Network Road Classification
PEMS	Portable emissions monitoring systems
PM_{10}	Particulate matter smaller than 10 microns
$PM_{2.5}$	Particulate matter smaller than 2.5 microns
PM_{BT}	Particulate matter from brake and tyre wear
T+T	Tonkin & Taylor Ltd
TIM	Traffic Impact Model
TLA	Territorial local authorities
VEMT	Vehicle Emissions Mapping Tool
VEPM	Vehicle Emissions Prediction Model
VFEM	Vehicle Fleet Emissions Model
VKT	Vehicle kilometres travelled
WHO	World Health Organization

APPENDIX B DEFAULT VEPM INPUTS

Input	Description*
Average trip length	9.1 km taken from the Household Travel Survey 2010 produces by the Land Transport Safety Authority (LTSA).
Calculated fleet composition data	The percentage VKT for each vehicle category is calculated within VEPM based on the default fleet data for the year selected. If the user defines the % of VKT by vehicle category, the default fleet data is adjusted proportionally.
Load factor for HCVs	Default loading factors for HCVs is 50%. Other available options are 0% and 100%.
Petrol/diesel fuel type	The default fuel type correlates with the fuel that was, or is, expected to be available at the analysis year. These are specified in a *'Fuel types'* worksheet in VEPM.
Cold start	Cold start emissions are estimated in the model for each vehicle class except HCVs. Cold start emissions are affected by the ambient temperature and average trip length. Cold start emissions are not available for HCVs as it is assumed these vehicles spend the majority of their life in use, hence why cold start emissions are not a significant factor in their operation.
Degradation	This allows for degradation of emissions over time. Default is to consider degradation for vehicles in VEPM.
Percentage catalytic converters not working • New vehicle • Old vehicle	Default value for: • Old vehicles is 15% based on MoT data, and is applied to petrol vehicles 11 years and older. There is no option in VEPM to estimate the percentage of removed or broken equipment for diesel vehicles. • New vehicles is 0% for all vehicles 11 years and younger.
Number of axles	The amount of particulate matter from brake and tyre wear is calculated based on the average number of axles for each vehicle class. Default values are used based on vehicle class.
Brake and type wear PM output	The size fraction of particulate matter from brake and tyre wear is selectable. Default is PM_{10}.

*Based on VEPM6.1 (2020)